INVESTIGATING HEAVY METAL UPTAKE BY PLANTS IN THE COAL BELT OF KOGI EAST, NIGERIA

By

Osseini U.E, Rabiu, M.*, Edicha, J.A., Hassan, S.M., and Okono, V.

Department of Geography and Environmental Management, University of Abuja, Nigeria
*Corresponding Author's Email: rabiu.muhammed111@gmail.com

ABSTRACT

This study investigates the uptake of heavy metals by plants in the coal belt of Kogi East, Nigeria, focusing on the Ika-Ogboyaga and Okaba mine sites within the Omala/Ankpa LGA. Using a table of random numbers, sampling plots were selected, and plant species growing on both contaminated and uncontaminated sites were harvested. The plants collected include *Ampelopteris prolifera, Paspalum dilatatum, Imperata cylindrica, Cymbopogon citratus,* among others. Samples were transported to the Federal University of Technology, Minna Central Research Laboratory, where they were processed and analyzed for heavy metals content using Atomic Absorption Spectrophotometry (AAS-VGP 210). Results indicated significant variations in heavy metal concentrations across different plant species and sites, with some values exceeding WHO permissible limits. For instance, at the Ika-Ogboyaga mine site, *Ampelopteris prolifera* showed zinc concentrations of 2.8±0.14 mg in leaves and 2.84±0.02 mg in roots, while *Cymbopogon citratus* had copper levels of 0.46±0.07 mg in leaves. At the Okaba mine site, *Afromomum daniellii* recorded zinc concentrations of 2.345±0.41 mg in leaves and 2.06±0.01 mg in roots, and *Afromomum melegueta* showed copper levels of 0.5±0.09 mg in leaves. The control site (Abache) had significantly lower concentrations, such as *Byrsocarpus coccineus schum* with zinc levels of 1.51±0.69 mg in leaves. ANOVA results demonstrated significant spatial variation in the concentrations of zinc (F(2) = 138.1956, P = 1.37E-04), copper (F(2) = 137.1485, P = 1.64E-05), iron (F(2) = 336.8571, P = 2.66E-04), manganese (F(2) = 203.9159, P = 1.05E-04), and lead (F(2) = 29.2703, P = 1.79E-06). The study recommended regular monitoring of heavy metal concentrations in both soil and plants within and around coal mining areas to detect and address contamination early

Keywords: Coal, Heavy Metal, Mining, Plant contamination

INTRODUCTION

The global mining sector plays a crucial role in generating income, employment, economic growth, development, and competitive advantage (Jerome 2003; Oelofse et al., 2008). However, mining also poses significant threats and hazards to ecosystems. Nigeria has been actively involved in solid mineral exploitation for decades, boasting over 34 solid minerals, including coal, tin, columbite, gold, lead, zinc, thorium, lignite, uranium, and tantalum, spread across more than 450 locations (Mining Journal, 2006). This activity has introduced potential environmental hazards and risks (Lazareva & Pichler 2007; Othman & Al-Masri 2007; Li et al., 2014). Mining waste lands are an inevitable by-product, resulting in significant soil degradation (Liu et al., 2003; Li et al., 2014).

Soils are often the ultimate sink for heavy metals released into the environment due to their high metal-scavenging capacity (Banat et al., 2005; Tomiyama et al., 2020). However, excessive contaminants degrade soil quality and pose hazards to human health through direct contact or indirectly via the food chain (soil-plant-human or soil-plant-animal-human). Certain hazardous elements can bioaccumulate in food crops (Wuana & Okieimen, 2011). For example, cadmium (Cd), manganese (Mn), and arsenic (As) have been reported to accumulate in food crops like rice and vegetables (Senoro et al., 2020).

As a result, contaminated soils become unsuitable for agriculture since crops grown on such soils are unsafe for consumption. Soil pollution can also cause harm through inhalation of contaminated dust, erosion into municipal waterways, and direct ingestion (geophagia) (Ministry of Environment [MOE], 2010). Inhalation of contaminated dust is a known cause of lead poisoning in Kabwe, Zambia (Silwamba et al., 2020). Also, in Nigeria Aliyu, (2024) reported high concentration of lead in water and soils in Bagega, Zamfara state.

Geophagia is common in many African and South American countries, especially among children and pregnant and breastfeeding women (Woywodt & Kiss, 2002), and is increasingly observed in Western societies (Reeuwijk et al., 2013). Consuming contaminated clay poses a significant health risk as it often exceeds safe daily exposure levels (Odongo et al., 2016).

The solid mineral mining landscape in Nigeria is predominantly occupied by artisanal and small-scale miners (ASMs), whose operations are largely informal and often go unregulated by the government. The widespread activities of these artisanal and small-scale miners have severely impacted on the physical environment. Most mining operations in Nigeria involve open cast mining, which is particularly harmful to the ecosystem. These ecological impacts include the loss of prime agricultural land, forest cover, pollution of water resources, air quality, and biodiversity. The activities of ASMs have resulted in numerous abandoned open mines and derelict landscapes (Mining Journal, 2006).

Mining of solid minerals such as coal can lead to significant environmental degradation. Natural forests and croplands are typically the first to be affected during coal exploration and exploitation. The open cast mining method is employed in the coal mines in Ankpa and Omala Local Government Areas (LGAs) of Kogi State. This strip mining process involves removing the overburden to expose the coal, which is then extracted using large cranes and trucks. It is well-documented that coal mining and its associated uses have various detrimental effects on the ecosystem, impacting the surrounding landscape, watercourses, flora and fauna, air quality, groundwater, and the social fabric of local communities (Thomas 2002).

Notably, coal mining in the current study areas has not been subjected to Environmental Impact Assessments, resulting in a lack of baseline ecological data. Several studies have highlighted the high risk of contamination by heavy metals and hazardous elements due to coal mining in Kogi State's ecosystems. For example, Ameh et al. (2021) assessed the seasonal variations of toxic metal pollution in soil and sediment around the Okaba Coal Mine area, while Oloche et al. (2019) evaluated the impact of coal mining on water quality in Nigerian water sources. Additionally, Ekwule et al. (2021) assessed heavy metal concentrations in the soil of the Odagbo area, Kogi State.

However, none of these studies have examined the implications of coal mining on plant species in the study area, which represents a significant research gap. Thus, this study aims to address this gap.

THE STUDY AREA

Ankpa LGA lies between Longitudes 7°36′ E to 7°39′ E and Latitudes 07°23′ N to 07°26′ N (Figure 1). Ankpa has an area of 1,200km^2 and a population of 267,353 at the 2006 census (Ishaka, 2012). While, the projected population to 2023 is put to be 400,779. Omala Local Government Area lies between Latitudes 07°30'48″N - 08°02'10″N and Longitudes 07°21'27″E - 07°50'45″E of the Greenwich Meridian with an aerial coverage of 1.667km^2 and a population of 108,402 at the 2006 census (Ishaka, 2012). Also, the projected population to 2023 is put to be 162,502 in 2023.

Ankpa and Omala falls within the Nigeria meteorological zone that is characterized by warm temperature days and moderately cool nights. Two distinct climatic divisions are demarcated as the dry and rainy seasons representing two broad periods of significant but contrasting variations of weather parameters. The area has warm Tropical Savanna Climate with clearly marked wet and dry seasons (Ali, 2010). Rainfall is well distributed and is of double maxima (Iloeje, 1972). The amount of rainfall ranges between 1,000mm to 1,750mm. Temperature is moderately high throughout the year, averaging 25°C. The maximum temperature of the area lies between 29.7°C - 35.6°C while the minimum temperature ranges between 23.3°C - 25.2°C (Ali, 2010).

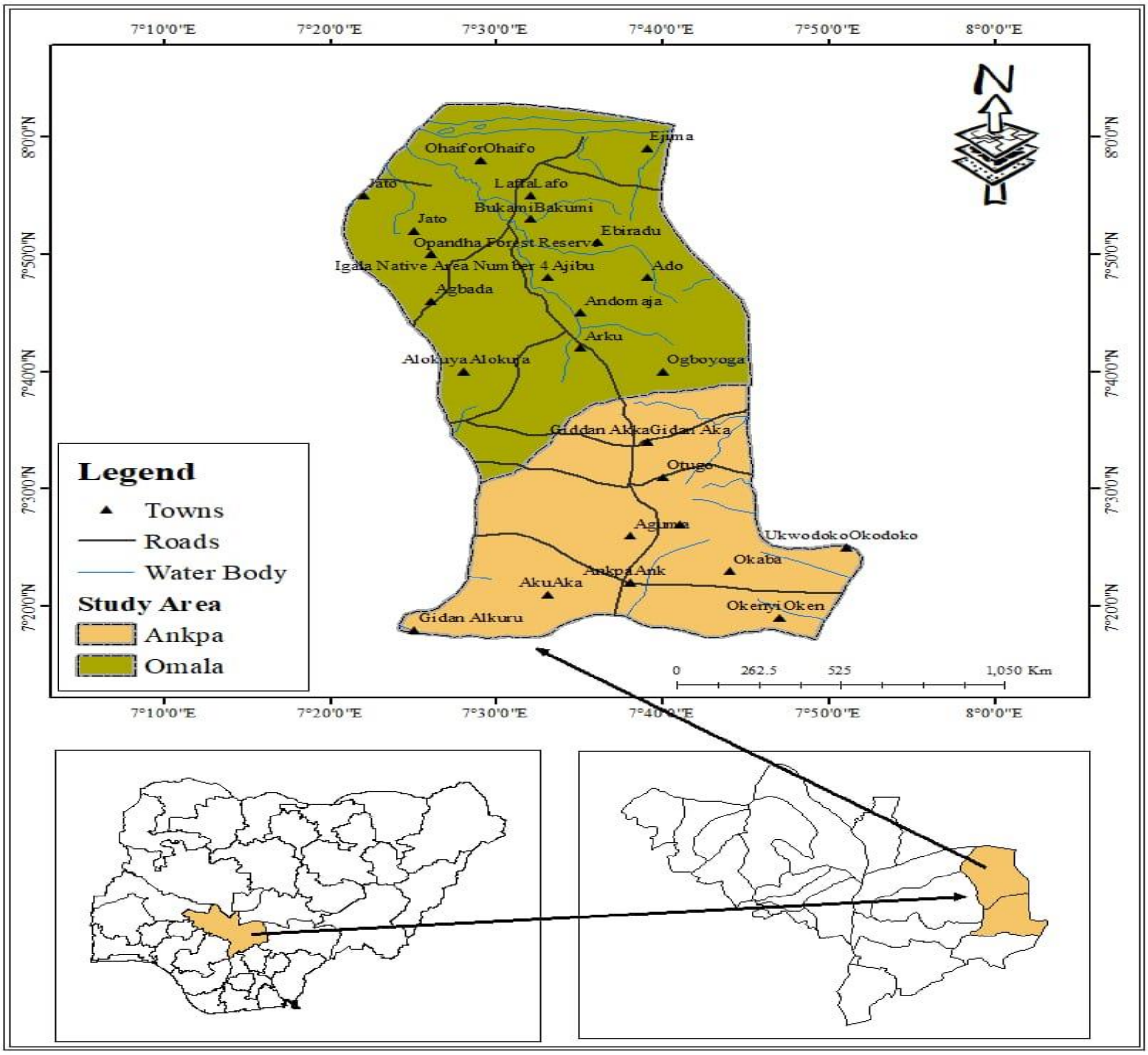

Figure 1: The Study area
Source: Geography Department Prince Abubakar Audu University (PAAU), Kogi State

MATERIALS AND METHODS

Sampling Procedure

The sampling frame of this study comprises of all the Coal mining sites within the Omala/Ankpa LGA, Kogi mine district and these include; Okaba, Odagbo (Ojoku district), Ogboyaga (Ika) and Okobo (Enjema). Ika-Ogboyaga and Okaba mine sites were selected for this study. This was done with the use of the table of random numbers, this was achieved using the formula for table of Random Numbers using the Microsoft excel Software Package. The Microsoft Excel has a function to produce random numbers. The function can be set to any range; the number of communities identified in the study area is 4, therefore, the range is within 1 to 4. The function is given below

= INT (4*RAND())+1

The **INT** eliminates the digits after the decimal, the 4* creates the range to be covered, and the **+1** sets the lowest number in the range. This is presented on the Table 1.

Table 1: Table of random numbers for identified communities

Communities	Random Numbers
Odagbo	3
Okaba	1
Okobo	4
Ika-Ogboyaga	2

The plants for the study were obtained from the Ika-Ogboyaga and Okaba mine sites with a control in Abache (5km away). A 50m×50m quadrat plot was constructed across each of the mined and unmined study sites. Plant samples were taken in replicates (three replicates for each sample) from the midpoint of each randomly selected plot having the following coordinates 7.651892N, 7.685042E, 7.651993N, 7.685173E and 7.66047N, 7.665426E (Mine sites) and 7.3551N, 7.6407E, 7.352933N, 7.649574E and 7.348847N, 7.644081E (Control site). The plants parts collected included the roots and leaves, the plants collected include; *Ampelopteris prolifera* (Walking Fern), *Paspalum dilatatum* (Dallis grass), *Imperata cylindrical* (Cogon grass or Lalang grass), *Cymbopogon citrutus* (Lemongrass), *Antaris toxicarig* (Antiaris or Ipoh tree), *Allophylus africanus* (African false currant), *Afromomum daniellii* (Bitter ginger or African cardamom), *Annona senegalensis* (African custard apple or Wild soursop), *Afromomum melegueta* (Grains of paradise or Alligator pepper), *Asphilla Africana* (Wild sunflower), *Cola nitda* (Kola nut), *Daniellia oliveri* (African copaiba balsam tree), *Bambusa vulgaris* (Common bamboo), *Moringa olifera* (Moringa), *Vitex doniana sweet* (Black plum or African oak), *Budyrospermum paradoxum* (Shea tree), *Burkea africana* (African teak) and *Anthocleista djalonensis A* (Cabbage tree).

The plant samples were transported to the Federal University of Technology, Minna Central Research Laboratory in labelled packets. Plant samples were washed with tap water to remove soil and then rinsed with distilled deionised water. The roots were separated from the shoots with a stainless-steel knife. They were air-dried for one week at room temperature by spreading them on thin cellophane paper, followed by oven drying at 50°C for 48 hours before sample preparation and analysis.

Plant chemical analysis

Oven dried plant samples (Leaves and Roots) were put in different crucibles and ashed in a furnace at 65°C for 2 hours. A quantity of the ash (1 g) from each plant sample was weighed separately into a beaker. To each, 3 ml of concentrated HCl and 1 ml of concentrated HNO_3 were added and heated on a hot plate at 100°C for 10 minutes and left to cool at room temperature. The solutions were topped with distilled deionized water to the 50 ml mark and filtered through a Whatman filter paper (Grade No. 41) before determination of Heavy metals using AAS-VGP 210.

Data Analysis

Mean concentrations of heavy metals in the plants parts (leaves and root) was computed using Microsoft Excel 2010. ANOVA was used to test for variations in individual concentrations in each species found in the different locations. Descriptive tools included averages, tables and charts for easy understanding of the pattern and variability in the concentration of heavy metals in the plant parts in the study area.

RESULTS AND DISCUSSION

Mean Levels of Heavy Metals concentration in Plant Parts in Ika-Ogboyaga Mine Site

The concentration of heavy metals in the roots and leaves of plants in Ika-Ogboyaga Mine Site were examined and the result is presented in Figures 2-6.

Figure 2 shows that *Ampelopteris prolifera* had the highest concentration of Zinc in its leaf (2.8±0.14 mg) and its roots (2.84±0.02mg), this is closely followed by *Imperata cylindrical* with mean values of 2.47±0.60 mg and 2.57±0.38 in its leaf and roots. In the same vein, *Cymbopogon citrutus* have mean values of 2.42±0.53 mg and 2.54±0.01 mg in its leaf and roots. Also, *Antaris toxicarig* have mean values of 2.06±0.01 and 2.47±0.33 mg in its leaf and roots. While, *Ampelopteris prolifera* had mean values of 2.055±0.03 and 2.355±0.21 mg in its leaf and roots respectively. All the values observed in the plant parts were all above the permissible value of Plant (0.60) (WHO, 1996).

Zinc is an essential micronutrient for plant growth although uptake in excess to the plant requirements result in toxic effects (Monni et al., 2000). Zinc toxicity in plants have been found to limit the growth of both root and shoot (Choi et al., 1996). Zinc toxicity also causes chlorosis in the younger leaves, which can extend to older leaves after prolonged exposure to high soil Zn levels (Ebbs & Kochian, 1997).

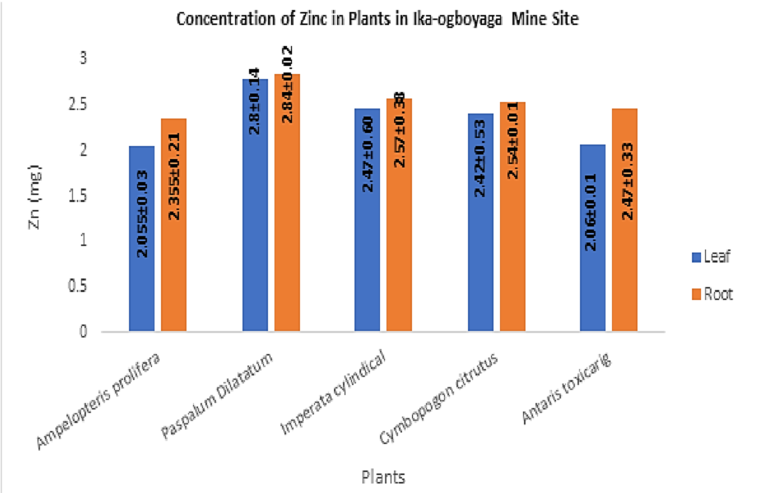

Figure 2: Concentration of Zinc in Plants in IKa-Ogboyaga Mine Site

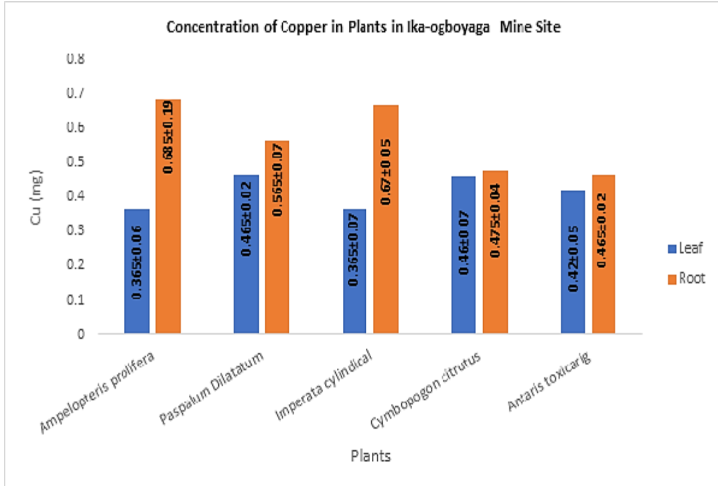

Figure 3: Concentration of Copper in Plants in IKa-Ogboyaga Mine Site

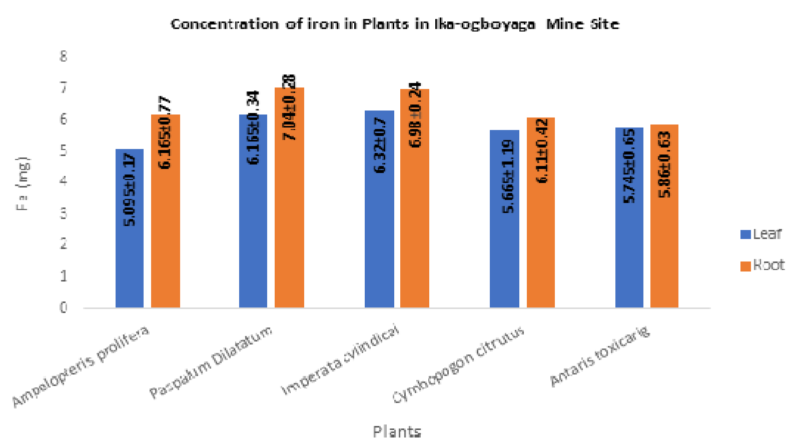

Figure 4: Concentration of Iron in Plants in IKa-Ogboyaga Mine Site

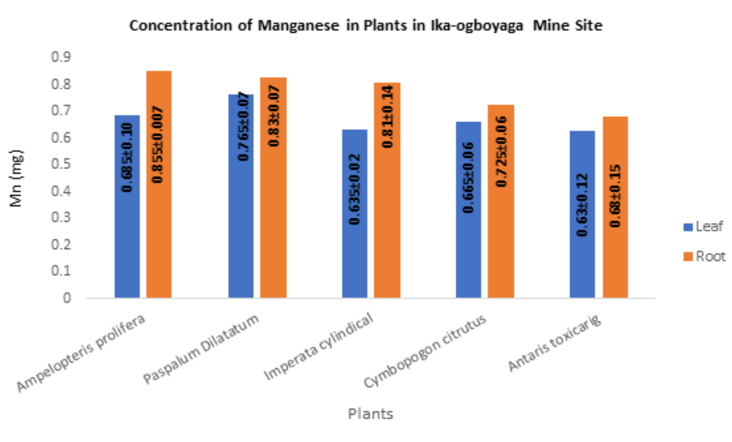

Figure 5: Concentration of Manganese in Plants in IKa-Ogboyaga Mine Site

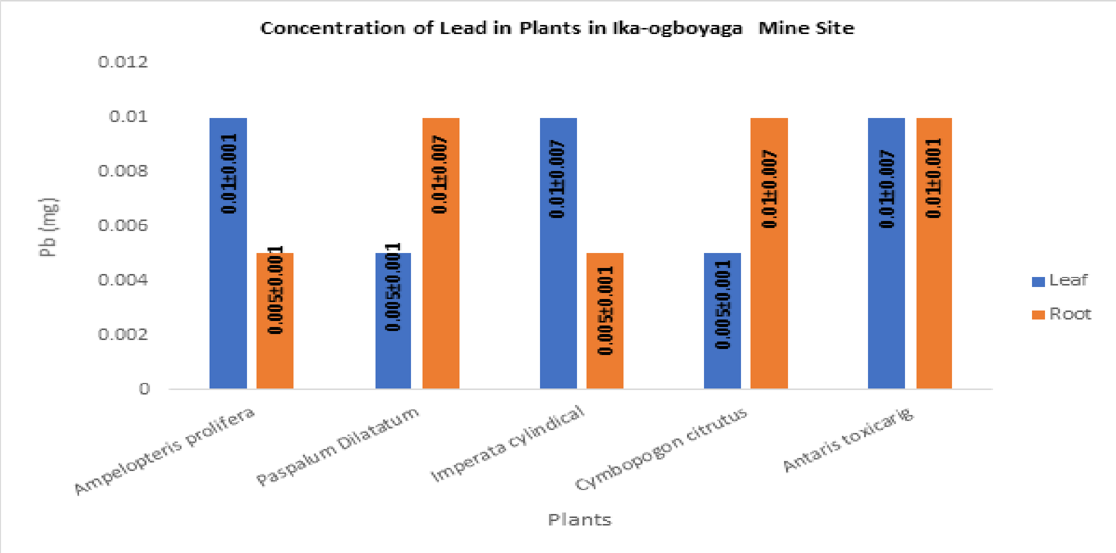

Figure 6: Concentration of Lead in Plants in IKa-Ogboyaga Mine Site

Also, Figure 3 shows that *Cymbopogon citrutus* and *Paspalum dilatatum* had the highest concentration of copper in their leaf with mean values 0.46±0.07 and 0.465±0.02mg respectively. This is closely followed by *Antaris toxicarig*, *Imperata cylindrical* and *Ampelopteris prolifera* with mean values 0.42±0.05, 0.365±0.07 and 0.365±0.06 respectively. similarly, *Ampelopteris prolifera* and *Imperata cylindrical* had the highest values of copper in their roots with mean values 0.685±0.19 and 0.67±0.05 mg, this is closely followed by *Paspalum dilatatum*, *Cymbopogon citrutus* and *Antaris toxicarig* with mean values 0.565±0.07, 0.475±0.04 and 0.465±0.02 mg respectively. These values were all within the permissible limits of the WHO 10 mg).

At toxic levels Cu reduces the absorption of water and mineral nutrients(Shabbir et al., 2020), promotes oxidative stress (Nazir et al., 2019) and affects photosynthesis (Cambrollé et al., 2015), causing reduced growth (Marques et al., 2018) and plant production (Shabbir et al., 2020).

Figure 4 shows that *Imperata cylindrical* has the highest concentration of iron in its leaf with a mean value of 6.32±0.7 mg, this is closely followed by *Paspalum dilatatum, Antaris toxicarig*, *Cymbopogon citrutus* and *Ampelopteris prolifera* with mean values 6.165±0.34, 5.745±0.65, 5.665±1.19 and 5.095±0.17 mg respectively. in the same vein, the figure shows that *Paspalum Dilatatum* had the highest concentration iron in its root with mean value 7.04±0.28, this is also closely followed by *Imperata cylindrical, Ampelopteris prolifera, Cymbopogon citrutus and Antaris toxicarig* with mean values of 6.98±0.24, 6.165±0.77, 6.11±0.42 and 5.86±0.63 mg respectively.

Also, the figure indicates that the iron concentration for all the plants in the study area were below the standard stipulated by WHO for plants (50 Mg). The findings disagree with the result of Nazir et al. (2015) who reported concentration of iron that are higher than WHO standard in Tanda Dam Kohat. Iron is an essential micronutrient for almost all living organisms because it plays critical role in metabolic processes such as synthesis, respiration and photosynthesis. the low concentration reported in this study imply that the plants will have problem with the synthesis of chlorophyll which is essential for the maintenance of chloroplast structure and function.

Figure 5 shows that *Paspalum dilatatum* has the highest concentration of Manganese in its leaf with a mean of 0.765±0.07 mg, this is closely followed by *Ampelopteris prolifera,* *Cymbopogon citrutus*, *Imperata cylindrical* and *Antaris toxicarig* with mean values of 0.685±0.10, 0.665±0.06, 0.635±0.02 and 0.63±0.12 mg respectively. Similarly, the figure shows that *Ampelopteris prolifera* has the highest concentration of manganese in its root with mean value 0.855±0.007, this is closely followed by *Paspalum Dilatatum, Imperata cylindrical, Cymbopogon citrutus* and *Antaris toxicarig* with mean values of 0.83±0.07, 0.81±0.14, 0.725±0.06 and 0.68±0.15 respectively. The values observed were all within the permissible limits of the WHO (11mg).

Manganese (Mn) is an essential plant mineral nutrient, playing a key role in several physiological processes, particularly photosynthesis. Mn toxicity can trigger oxidative stress and disrupt photosynthesis, which may result in the generation of interveinal chlorosis in young leaves, necrotic dark spots on mature leaves, and crinkled leaf (Bachman and Miller, 1995).

Figure 6 shows that *Ampelopteris prolifera*, *Imperata cylindrical* and *Antaris toxicarig* had high concentration of lead in their leaf with mean values 0.01±0.001, 0.01±0.007 and 0.01±0.007 mg, while *Paspalum dilatatum* and *Cymbopogon citrutus* had mean values of 0.005±0.001 mg. similarly, the figure shows that Cymbopogon *citrutus, Paspalum dilatatum* and *Antaris toxicarig* had the high concentration of lead in their roots with mean values 0.01±0.007 mg respectively. all the values observed were within the permissible limits of the WHO (0.3mg). Lead (Pb) is one of the ubiquitously distributed most abundant toxic elements in the soil. It exerts adverse effect on morphology, growth and photosynthetic processes of plants.

Mean Levels of Heavy Metals concentration in Plant Parts in Okaba Mine Site

The study also investigated the level of heavy pollution using plant species in the Okaba mine site. The results are presented in Figures 7-11. Figure 7 shows that the concentration of Zinc in plant samples at the Okaba mine site were far higher than that observed at the Ika-ogboyaga mine site. The figure shows that *Afromomum daniellii* had the highest concentration of Zinc in its leaf with mean values of 2.345±0.41mg, this is closely followed by *Annona senegalensis*, *Asphilla Africana* and *Afromomum melegueta* with mean values of 2.335±0.38, 2.32±0.42 and 2.285±0.36 mg respectively. Also, the figure shows that *Annona senegalensis* had the highest concentration of Zinc in its root with mean value of 2.615±0.13 mg, this is also closely followed by *Afromomum melegueta*, *Asphilla Africana*, *Afromomum daniellii* and *Allophylus africanus* with mean values of 2.27±0.26, 2.145±0.13, 2.06±0.01 and 2.02±0.01 mg respectively. This finding shows that all the values observed were far above the permissibly limit of the WHO (0.6mg).

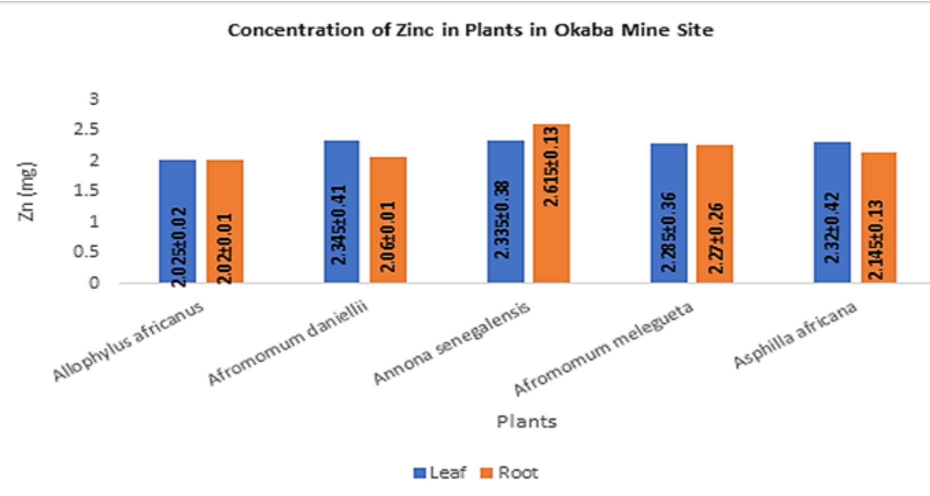

Figure 7: Concentration of Zinc in Plants in Okaba Mine Site

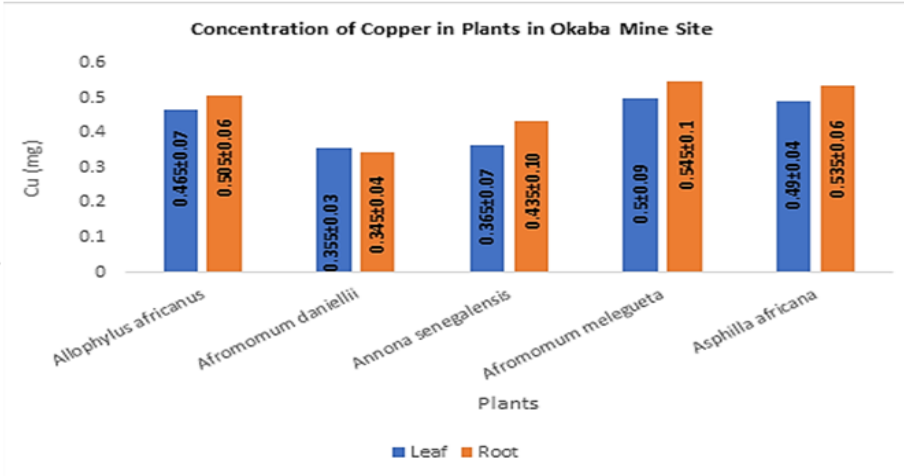

Figure 8: Concentration of Copper in Plants in Okaba Mine Site

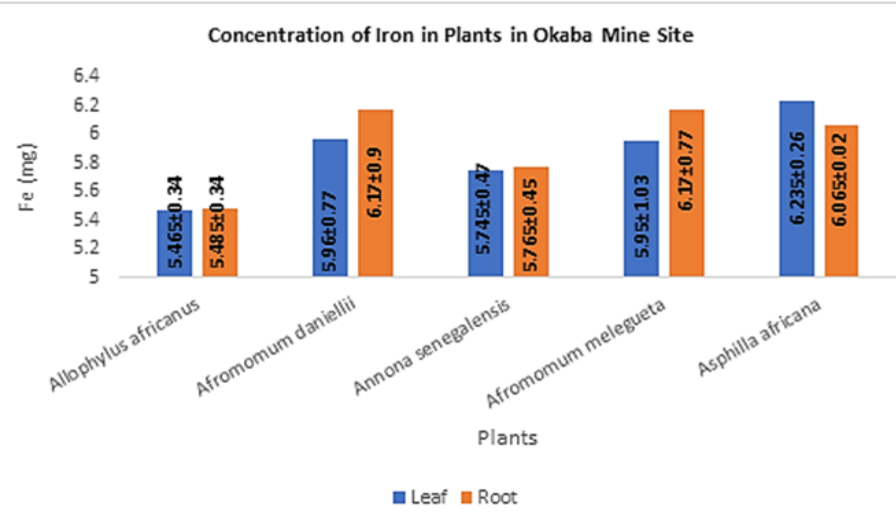

Figure 9: Concentration of Iron in Plants in Okaba Mine Site

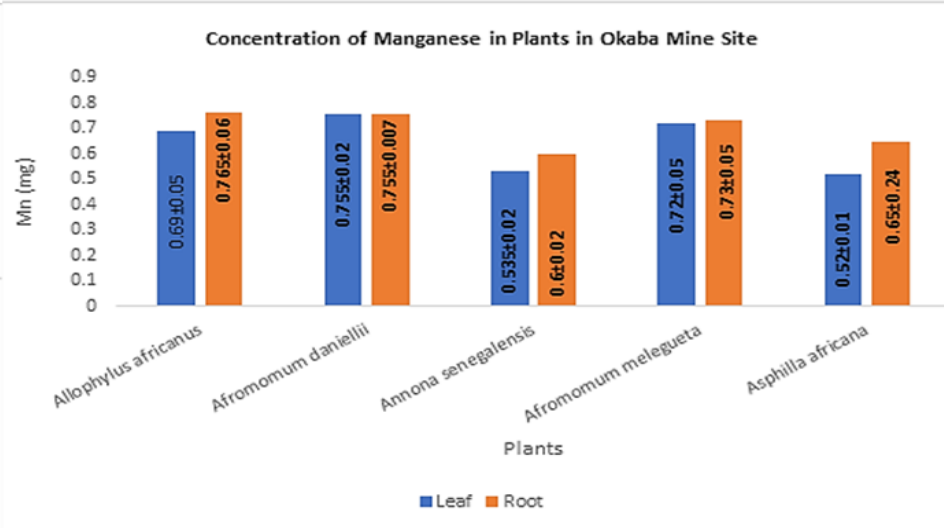

Figure 10: Concentration of Manganese in Plants in Okaba Mine Site

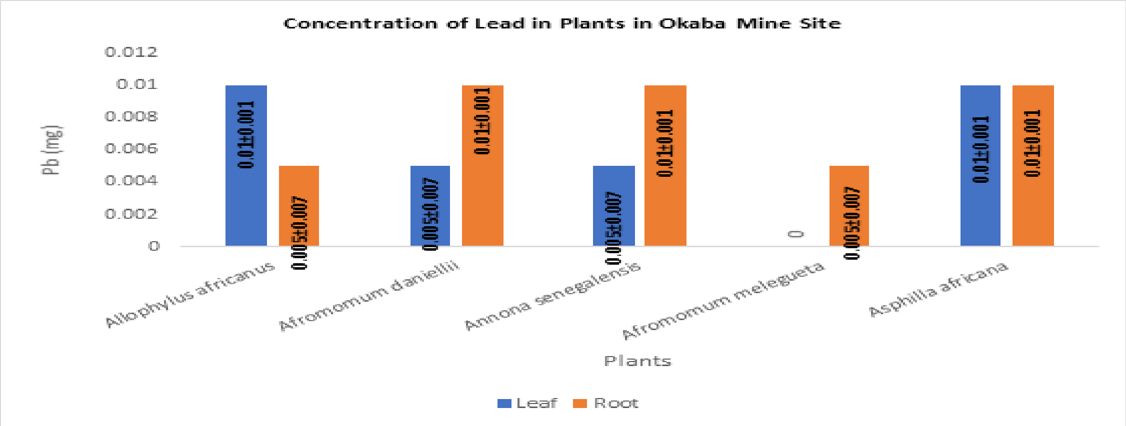

Figure 11: Concentration of Lead in Plants in Okaba Mine Site

High concentrations of Zinc can cause toxicity in plants. The general symptoms are stunting of shoot, curling and rolling of young leaves, death of leaf tips and chlorosis (Daviscarter & Shuman, 1993).

Figure 8 shows that *Afromomum melegueta* had the highest concentration of Copper in its leaf with mean of 0.5±0.09 mg, this is closely followed by *Asphilla Africana*, *Allophylus africanus*, *Annona senegalensis* and *Afromomum daniellii* with mean values of 0.49±0.04, 0.465±0.07, 0.365±0.07 and 0.355±0.03 mg respectively. the figure further reveals that *Afromomum melegueta* had the highest concentration of Copper in its root with mean value of 0.545±0.1 mg, also this is closely followed by *Asphilla Africana*, *Allophylus africanus*, *Annona senegalensis* and *Afromomum daniellii* with mean values; 0.535±0.06, 0.505±0.06, 0.435±0.10 and 0.345±0.04 mg respectively. The values observed were also within the permissible limits of the WHO (73.2 mg).

Also, Figure 9 shows that *Asphilla Africana* had the highest concentration of Iron in its leaf with mean value of 6.235±0.26 mg, this is also closely followed by *Afromomum daniellii*, *Afromomum melegueta*, *Annona senegalensis* and *Allophylus africanus* with mean values of 5.96±0.77, 5.95±1.03, 5.745±0.47 and 5.465±0.34 mg respectively. Also, the figure shows that *Afromomum melegueta* and *Afromomum daniellii* had the highest concentration of Iron in their roots with mean values 6.17±0.77 and 6.17±0.9 mg respectively.

Figure 10 shows that *Afromomum daniellii* had the highest concentration of Manganese in its leaf with mean value 0.755±0.02mg, this is closely followed by *Afromomum melegueta*, *Allophylus africanus*, *Annona senegalensis* and *Asphilla Africana* with mean values of 0.72±0.05, 0.69±0.05, 0.535±0.02 and 0.52±0.01mg respectively. the figure further shows that *Allophylus africanus* had the highest concentration of Manganese in its root with mean value; 0.765±0.06mg, this is closely followed by *Afromomum daniellii*, *Afromomum melegueta*, *Asphilla Africana* and *Annona senegalensis* with mean values of 0.755±0.007, 0.73±0.05, 0.65±0.24 and 0.6±0.02mg respectively.

Figure 11 shows that *Allophylus africanus* and *Asphilla Africana* had the highest concentration of Lead in their leaves with mean value 0.01±0.001mg, this is closely followed by *Afromomum daniellii* and *Annona senegalensis* with mean values of 0.005±0.007mg respectively. in the same vein, the figure shows that *Afromomum daniellii*, *Annona senegalensis* and *Asphilla Africana* had the highest concentration of Lead in their roots with mean values 0.01±0.001mg. Also, all the values observed were below the permissible limits of the WHO (0.3mg).

Lead (Pb) is one of the ubiquitously distributed most abundant toxic elements in the soil. It exerts adverse effect on morphology, growth and photosynthetic processes of plants. Lead is known to inhibit seed germination of *Spartiana alterniflora*, *Pinus helipensis* (Morzeck and Funicclli, 1982).

Presence of Heavy Metals in Plant Parts in Abache (Control Site)

The Presence or absence of heavy metal in plant parts from a control site was also investigated and this is presented in Figures 12-16.

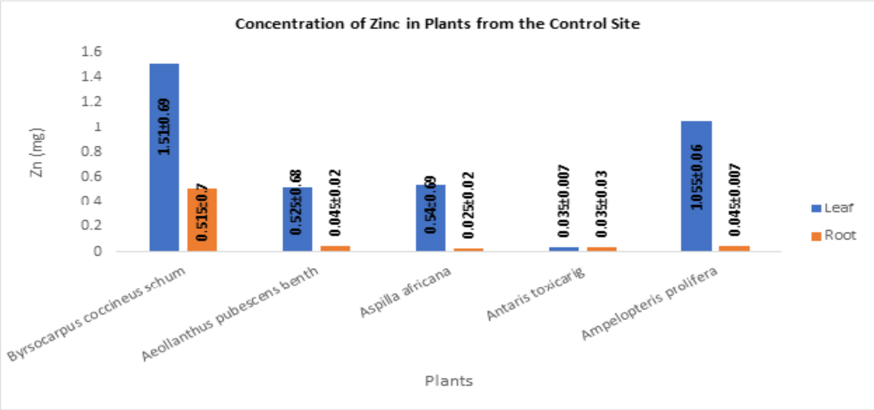

Figure 12: Concentration of Zinc in Plants from the Control Site

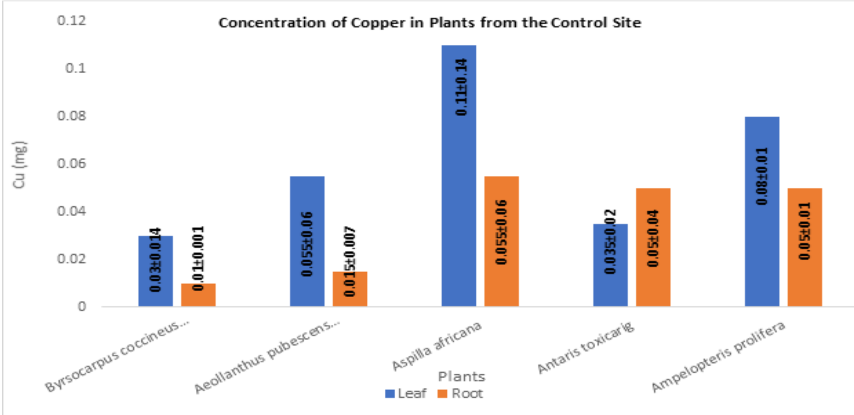

Figure 13: Concentration of Copper in Plants from the Control Site

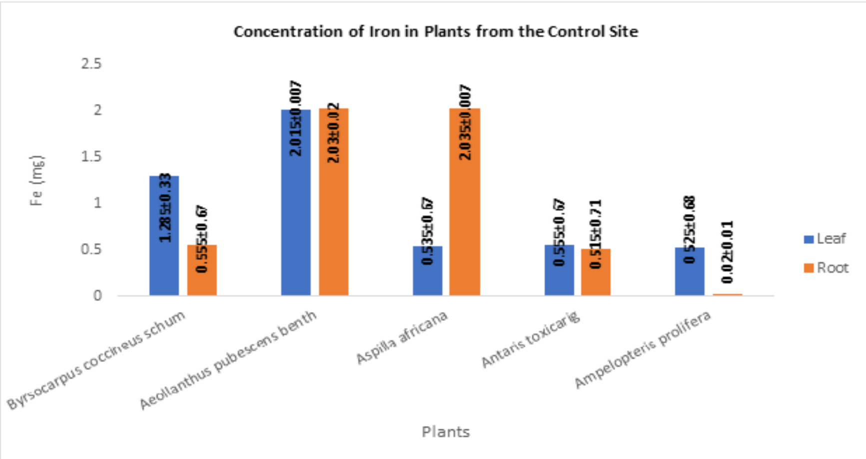

Figure 14: Concentration of Iron in Plants from the Control Site

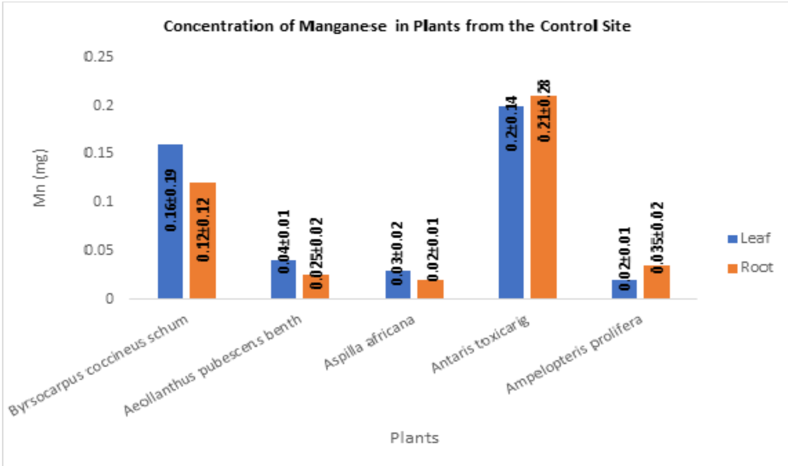

Figure 15: Concentration of Manganese in Plants from the Control Site

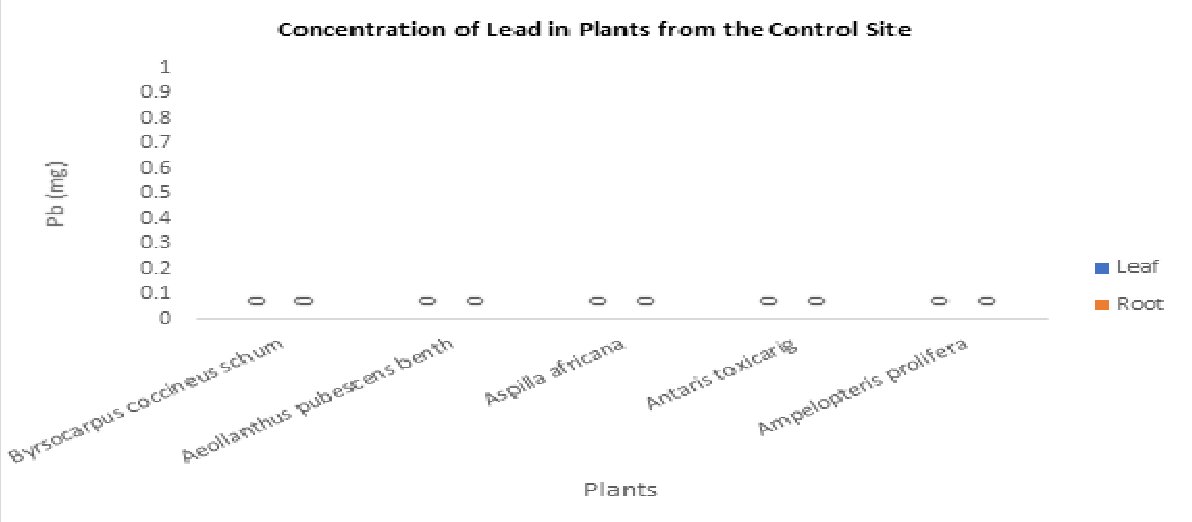

Figure 16: Concentration of Lead in Plants from the Control Site

Figure 12 shows that *Byrsocarpus coccineus schum* had the highest concentration of Zinc in its leaf with mean value of 1.51±0.6 mg, this is also followed by *Ampelopteris prolifera* with mean value 1.055±0.06mg. the figure further shows that *Byrsocarpus coccineus schum* had the highest concentration of Zinc in its roots with mean value of 0.515±0.7 mg respectively.

Similarly, Figure 13 shows that *Aspilla africana* had the highest concentration of Copper in its leaf with mean value 0.11±0.14 mg, this is closely followed by *Ampelopteris prolifera* and *Aeollanthus pubescens benth* with mean values 0.08±0.01 and 0.055±0.06mg respectively. also, the figure shows that *Aspilla africana, Antaris toxicarig and Ampelopteris prolifera* had the highest concentration of Copper in their roots with mean values of 0.055±0.06, 0.05±0.04 and 0.05±0.01 mg respectively.

Figure 14 shows that *Aeollanthus pubescens benth* has the highest concentration of Iron in its leaf with mean value 2.015±0.007 mg, this is closely followed by *Byrsocarpus coccineus schum*, *Antaris toxicarig*, *Aspilla africana* and *Ampelopteris prolifera* with mean values of 1.285±0.33, 0.555±0.67, 0.535±0.67 and 0.525±0.68 mg respectively. Also, the figure shows that *Aeollanthus pubescens benth* and *Aspilla africana* had the highest concentration of Iron in their roots with mean values of 2.03±0.02 and 2.035±0.007 mg respectively.

Figure 15 shows that *Antaris toxicarig* and *Byrsocarpus coccineus schum* had the highest concentration of Manganese in their roots with mean values of 0.2±0.14 and 0.16±0.19mg respectively. in the same vein, the figure shows that *Antaris toxicarig* and *Byrsocarpus coccineus schum* had the highest concentration of Manganese in their roots with mean values of 0.21±0.28 and 0.12±0.12mg respectively.

Figure 16 shows that Lead was not detected in the control site.

The result presented in Figures 12-16 shows a spatial variation in the concentration of the various heavy metal analysed in this study. This is an indication that the mine sites are polluted due to coal mining activities.

Spatial Variation in the Levels of Heavy Metal Concentrations in Plant Species from Mine Sites and Control

The spatial variation in the concentrations of heavy metals in plant species from the mine sites and the control site is presented in Table 2.

Table 2: ANOVA for Spatial Variations in the Concentration of Heavy Metal

Zn	**ANOVA**						
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	49.49	2	24.74	138.19	1.37E-04	3.15
	Within Groups	10.20	57	0.17			
	Total	59.70	59				
Cu	ANOVA						
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	2.42	2	1.21	137.14	1.64E-05	3.15
	Within Groups	0.50	57	0.01			
	Total	2.92	59				
Fe	ANOVA						
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	333.88	2	166.94	336.85	2.66E-04	3.15
	Within Groups	28.24	57	0.49			
	Total	362.13	59				
Mn	ANOVA						
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	5.05	2	2.52	203.91	1.05E-04	3.15
	Within Groups	0.70	57	0.01			
	Total	5.76	59				
Pb	ANOVA						
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	0.00	2	0.00	29.27	1.79E-06	3.15
	Within Groups	0.00	57	1.29			
	Total	0.00	59				

NS=Not significant ($p \geq 0.05$)

Table 2 shows that there is a spatial variation in the concentration of Zn in the study area and this is statistically significant at *F ((df;2)* =138.19, P-value=1.37E-04. In the same vein, the table further shows that there is a spatial variation in the concentration of Cu in the study area and this is statistically significant at *F ((df;2)* =137.14, P-value=1.64E-05. Similarly, the table shows that there is a spatial variation in the concentration of Fe in the study area and this is statistically significant at *F ((df;2)* =336.85, P-value=2.66E-04. Also, the table shows that there is a spatial variation in the concentration of Mn in the study area and this is statistically significant at *F ((df;2)* =203.91, P-value=1.05E-04. The table further shows that there is a spatial variation in the concentration of Pb in the study area and this is statistically significant at *F ((df;2)* =29.27, P-value=1.79E-06.

This finding also corroborates the findings of Bhanu et al. (2014) who reported high concentration levels of heavy metal in Jharia Coal field (JCF) as compared to the control site in Jharkhand, India. This result indicates that the coal mining sites are highly polluted with heavy metal.

CONCLUSION

The study revealed significant levels of heavy metal contamination in plant species growing in the coal belt of Kogi East, Nigeria. The concentrations of zinc, copper, iron, manganese, and lead varied significantly across different species and sites, with some exceeding the WHO permissible limits. For instance, *Ampelopteris prolifera* and *Imperata cylindrica* showed high levels of zinc and copper, while iron concentrations remained below permissible limits. The results underscore the environmental impact of coal mining activities, emphasizing the need for monitoring and remediation efforts to mitigate heavy metal pollution.

Based on the findings of this study, the following recommendation are suggested:

- Regular Monitoring: Implement regular monitoring of heavy metal concentrations in both soil and plants within and around coal mining areas to detect and address contamination early.
- Phytoremediation: Utilize phytoremediation strategies employing plants like *Ampelopteris prolifera* and *Imperata cylindrica*, which have shown high metal uptake, to clean contaminated sites.
- Pollution Control Measures: Enforce stricter pollution control measures in coal mining operations, including proper waste disposal and the use of technologies to minimize emissions.
- Public Awareness: Increase public awareness and education on the potential health risks associated with heavy metal contamination and the importance of environmental conservation.
- The number of heavy metals considered in this work may not be enough to draw vivid conclusion on heavy metal impact; hence, others, such as arsenic, cobalt, Nickel, Cadmium and others should also be monitored.
- The state Government should instigate the mining companies to sign a Community Development Agreement (CDA) with the host communities so as to mitigate the impact of her activities on the communities.
- The State Ministry of Environment should set out enforcement policies that will require mining companies to carry out an Environmental Impact Assessment before commencing operations.

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